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Influence of tillage intensity and nitrogen placement on nitrogen uptake and yield in strip-tilled white cabbage (*Brassica oleracea* convar. *capitata* var. *alba*)

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ABSTRACT

Field grown vegetables with wide row spacing would likely benefit from the conservation tillage practice, strip-tillage, with regards to minimizing soil erosion or increasing soil moisture contents, but there are only few studies for strip-tilled vegetables at present. For this reason, a 2-year field experiment was performed in South West Germany to investigate the effect of strip-tillage under broadcast and placed nitrogen application on nitrogen availability and yield of white cabbage (*Brassica oleracea* convar. *capitata* var. *alba*). The treatments were fall strip-tillage (ST), intensive strip-tillage with tillage both in fall and spring (STi; all of them with broadcast nitrogen fertilization) and intensive strip-tillage with band-placed nitrogen (STi_pN). In 2013, a fifth treatment was added, which was ST additional sowing of *Phacelia* (*Phacelia tannacetifolia*) as a cover crop (ST_Phac). A conventional tillage treatment (MP; moldboard plowing) was used as the control. No significant differences in soil mineral nitrogen (SMN) were detected in spring (20 ± 5 kg N ha^{-1}) and at harvest time (5 ± 0.9 kg N ha^{-1}) between the MP and all strip-tillage treatments from 0–90 cm soil depth, except for significantly lower SMN contents in ST_Phac in spring 2013 (5 kg N ha^{-1}). During the growing period, the SMN contents in strip-tillage treatments tended to be higher than in the MP control. Results of nitrogen content in plants, N-uptake, and nitrogen use efficiency (NUE) showed higher values under ST compared to the more intensive strip-tillage treatments (STi and STi_pN). The cabbage yield ranged between 65 t ha^{-1} (MP) and 74 t ha^{-1} (ST) in 2012 and 50 t ha^{-1} (STi_pN) and 58 t ha^{-1} (MP) in 2013. The fall strip-tillage treatment (ST) seems to be as effective as the conventional moldboard plowing for white cabbage in terms of N availability and yield. These results could be used to apply or improve strip-till systems with respect to other similar vegetables, which are (i) exposed to high erosion risk because of the wide row spaces and (ii) which are dependent on high N demand for adequate growth.

1. Introduction

Conservation tillage, especially no-till, is the most effective way to reduce soil erosion and nitrate leaching, and to increase soil organic matter and water contents in soil (Triplett Jr. and Dick, 2008). In poorly drained soils, however, it is a great challenge to achieve similar yields to that of conventional tillage systems, when comparing yields to a no-till system. Reasons for a lower yield potential can be due to poor seedbed conditions, slower plant development, and impeded root growth under non-inversion tillage practices (Licht and Al-Kaisi, 2005). Furthermore, lower soil temperature, higher soil moisture, and slower mineralization under no-tillage can result in delayed early crop growth and finally lower yields (Alvarez et al., 1998). To avoid these negative effects, strip-tillage could be a viable option towards combining the benefits from no-till practices, such as erosion control, together with some of the advantages from conventional tillage practices with regards to the moldboard plow. Strip-tillage is a non-inversion tillage practice; it disturbs the row, but retains the inter-row space as untilled with all residues from the previous crop covering the soil (Vyn and Raimbault, 1993). Thus, less than one third of the total field area is tilled, and two-thirds of the area remains undisturbed. Particularly for maize (*Zea mays* L.), sugar beet (*Beta vulgaris*), and soybean (*Glycine max* L.), strip-tillage was tested successfully (Al-Kaisi and Kwaw-Mensah, 2007; Randall and Vetsch, 2008; Evans et al., 2010). For field grown vegetables, only few studies exist (Hoyt, 1999; Overstreet and Hoyt, 2008) although especially for vegetables the erosion risk is very high because of the

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high tillage intensity, large row spacing, and late soil covering by plants. Field grown vegetables, such as white cabbage (*Brassica oleracea* convar. *capitata* var. *alba*), have a high nutrient demand and a need of finely crumbled soil. The common way to produce high yielding white cabbage is to till the soil once by the moldboard plow, and then at least twice by a rotary harrow or a rotary cultivator to provide optimal conditions for planting and establishment of the young plants. No-tillage would seldom meet these requirements. Therefore, on the one hand, strip-tillage could be a solution to minimize the risk of soil erosion in vegetable production, and, on the other hand, help to maintain a high yield level. There is, however, still concern as to whether mineralization of nutrients in the soil would take place adequately, and whether the cabbage plants are able to take up the nutrients from the solid, untilled area in strip-till with high bulk density and potentially with poor root penetration (Kubota and Williams, 1967; Kay and Vandenbygaart, 2002).

Additionally, in the non-tilled zones, it is not possible to incorporate fertilizers so that broadcast fertilizer remains on the soil surface for a while after their application (Malhi et al., 1996). No incorporation consequences could then result in high volatilization losses (Mengel, 1982) and increased immobilization of nutrients if crop litter, containing a high C/N ratio, would then remain on the surface of the soil (Malhi et al., 2001). Hence, one approach to minimize the volatilization and to simultaneously increase N-uptake and nitrogen use efficiency (NUE) involves the utilization of fertilizer placement techniques (Malhi and Nyborg, 1990). Deep band fertilizing is frequently used in conservation tillage and consists of a band of fertilizer that is applied at a depth of 5–15 cm below the soil surface (Rehm, 1999). Nitrogen placement fertilization at 5–15 cm soil depths can produce greater root mass than with having N-fertilization at 0 cm depth or than from a broadcast fertilization only reaching the soil surface (Murphy and Zaurov, 1994).

For field grown vegetables, there have been no known investigations regarding the effects of a strip-tillage system combined with a band-placed nitrogen fertilization approach. For this reason, a 2-year field experiment with white cabbage was conducted to test the hypotheses that nitrogen uptake is less efficient in broadcast application than in band-placed application and, in combination with more frequently tilled strips (tillage in fall and spring), results in higher mineralization, better seedbed conditions, and finally in higher crop yields compared to strip-till treatment with less intense soil preparation (only fall preparation).

To prove these hypotheses following issues need to be clarified:

(1) What is the effect of strip-tillage and N-fertilization practices on the soil mineral nitrogen content and is there an improved nitrogen use efficiency by band-placed nitrogen fertilization compared to the broadcast application?
(2) What effect has two times strip-till and the fertilizer placement on plant establishment, N-uptake and yield of white cabbage?
(3) Is it possible to achieve a similar yield potential under strip-tillage than under conventional tillage?

2. Material and methods

2.1. Site and experimental design

The field experiment was performed in Southwest Germany at the experimental station Ihinger Hof of University of Hohenheim (48°44′N, 8°55′E) during 2011/2012 and 2012/2013. The average annual rainfall of the location is 690 mm, and the average annual temperature is 8.1 °C. The soil type of the fields was predominantly a stagnogleyic Cambisol, and the texture of the upper layer (0–20 cm) was a clay loam (CL), and the second layer (>20 cm) represented a silty clay (SiC) (FAO, 2006). The fields had a mean slope of 8% in south–north direction. In both experimental years, the experimental design was a randomized complete block design with four replicates with 6 m × 20 m per plot. In 2011/2012, four treatments were established, and in 2012/2013 a fifth treatment was added (Table 1). Treatment 1 was conventional tillage by a moldboard plow and rotary harrow (MP), treatments 2–5 were performed as strip-tillage. In treatment 2, strips were prepared only one time in fall, and cabbage was transplanted in spring without any further tillage (ST). A broadcast nitrogen fertilization was conducted. Treatments 3 and 4 had increased tillage intensity with strip preparation in fall and a shallow loosening of the strips by the strip-tiller in spring before transplanting. Additionally, stubble tillage was performed by a harrow after harvest of the previous crop winter triticale (cv. Talentro). In treatment 3, nitrogen was applied by broadcasting (STi) whereas in treatment 4 a band-placed nitrogen fertilization was conducted (STi_pN). In 2012/2013, treatment 5 was added, which was similar to ST, but *Phacelia* (*Phacelia tannacetifolia*) was sown as a cover crop after cereal harvest in 2012 (ST_*Phac*). The first tillage operation in ST, STi, STi_pN, and ST_*Phac* was done by a RTK-GPS based strip-tiller (Horsch 'Focus') on September 29th (2011) and on October 25th (2012). The strips were 20 cm deep and 20 cm wide. The second shallow loosening in STi and STi_pN was performed by the same strip-tiller on April 30th (2012) and May 14th (2013). White cabbage cv. Marcello (*Brassica oleracea* convar. *capitata* var. *alba)* was transplanted on 1st May (2012) and May 15th (2013), with 50 cm row distance in row and between row by a modified total-controlled transplanter (Checchi & Magli) with RTK-GPS guidance system for an exact transplanting.

2.2. Fertilization and plant protection

The crop requirement for potassium, phosphorous, and magnesium fertilization was determined according to IGZ fertilizer recommendations (Feller et al., 2011) by soil sampling in spring. An amount of 94 kg K_2O ha^{-1} and 45 kg MgO ha^{-1} was broadcast in

Table 1
Treatments and tillage operations for the experimental years 2011/2012 and 2012/2013.

Treatment	Tillage operation	N-fertilization	Year
Moldboard plowing(MP)	Moldboard plowing Rotary harrowing	Broadcast	2011/2012 2012/2013
Strip-tillage (ST)	Strip-tillage	Broadcast	2011/2012 2012/2013
Intensive strip-tillage, broadcast nitrogen fertilization(STi)	Strip-tillage in fall Strip-tillage in spring	Broadcast	2011/2012 2012/2013
Intensive strip-tillage, band placed nitrogen fertilization(STi_pN)	Strip-tillage in fall Strip-tillage in spring	Band placed	2011/2012 2012/2013
Strip-tillage, with *Phacelia* as cover crop in 2012(ST_*Phac*)	Strip-tillage in fall	Broadcast	2012/2013